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Eastern Pacific Hurricane Season of 1971

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ABSTRACT—The 1971 season was characterized by recurrent and persistent patterns of activity. A record 12 hurricanes and six tropical storms were counted. Satellite pictures and ship reports provided most of the clues to developing storms. U.S. Air Force Weather Reconnaissance provided most of the location, intensity, and structure information after development was underway.

Several of the hurricanes and storms rate special attention: Agatha, a small violent May hurricane, hit the village of Playa Azul, Mexico; Bridget did $40 million damage at Acapulco, Mexico; Denise, Francene, Olivia, and Priscilla had reported surface winds of 100 kt or more; Monica was described by reconnaissance (which could not penetrate) as the strongest ever seen in the area; Katrina was an elusive ministorm that caused floods at Los Mochis, Mexico; Lily, a violent, recurving hurricane, took 12 lives in Mexico and caught several ships in her hurricane-force winds; and Olivia had an earlier existence as Caribbean hurricane Irene.

1. SEASONAL STATISTICS

The long, active eastern Pacific hurricane season of 1971 began May 21 with the development of hurricane Agatha and ended November 28 with dissipation of tropical storm Sharon. Twelve of the 23 cyclones on which advisories and bulletins were issued reached hurricane intensity; five more hurricanes occurred than were recorded for any previous year. Six tropical cyclones reached tropical storm intensity, and five reached tropical depression intensity. Occurrence of hurricanes and tropical storms by month of beginning for the years 1966–71 is given in table 1; the period of record represents full operational satellite coverage in the eastern Pacific. Tracks of these 1971 storms are shown in figure 1. There were a total of 48 hurricane days and 47 tropical storm days; 2 days were recorded for each day with two storms (table 2). Three hundred and ten advisories were issued: 125 on storms of hurricane intensity and 185 on storms of tropical storm intensity. Eighty-nine bulletins were issued on tropical depressions.

The reason for the occurrence of the extraordinary number of intense hurricanes is not known, but undoubtedly anomalies in sea-surface water temperature contributed to their development. The National Marine Fisheries Service monthly anomaly charts of 1971 showed warmer than normal water in several areas: off the Central American coast for most of the season and along the coast of the Mexican mainland to the Gulf of California in June, July, and August. A large warm anomaly was present during June on waters that generated the July storms. Throughout the season, the Peru Current caused considerably lower than normal sea-surface temperatures in equatorial regions; large cold anomalies also were persistent 400 n.mi. south and southwest of the southern tip of Baja California.

Part of the increase in the number of hurricanes reported can be attributed to the dependable availability of reconnaissance aircraft and to the discovery, during reconnaissance flights, of hurricane winds in storms showing no eye on satellite pictures. In those cases, the eye was either hidden by a thick cirrostratus cap, or was insufficiently illuminated to be revealed by light and shadow contrast. The National Environmental Satellite Service (NESS) classification system (Anderson et al. 1969), which requires that an eye be visible for classification in category 3 or 4, was the principal basis for intensity

TABLE 1.—*Tabulation of hurricanes (Hu) and tropical storms (TS) in the eastern Pacific by month and year in which they began*

Year	May		June		July		Aug.		Sept.		Oct.		Nov.		Totals		
	Hu	TS	Hu	TS	Hu	TS	Hu	TS	Hu	TS	Hu	TS	Hu	TS	Hu	TS	Combined
1966			1				4		2	4		2			7	6	13
1967			1	2		4	2	2	1	2	2	1			6	11	17
1968				1		4	3	5	2	1	1	2			6	13	19
1969					1	2	1	1	1	3	1				4	6	10
1970	1			3	1	5	1	3		1	1	1		1	4	14	18
1971	1		1		5	2	2	2	2		1	1		1	12	6	18
6-yr total	2		3	6	7	17	13	13	8	11	6	7		2	39	56	95
Annual averages															6. 5	9. 3	15. 8

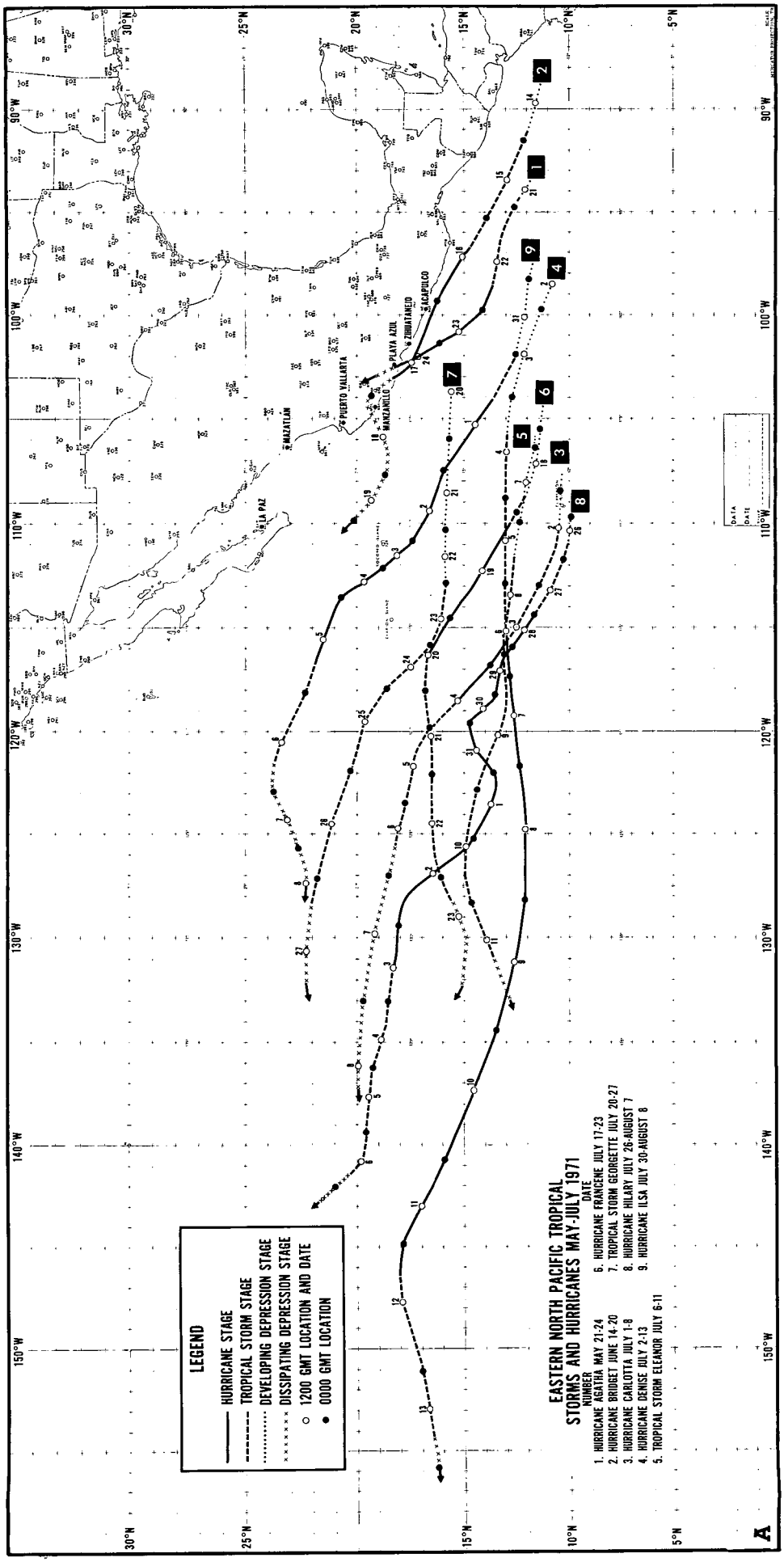

FIGURE 1.—Eastern North Pacific tropical storms and hurricanes during (A) May-July and (B) August-November 1971.

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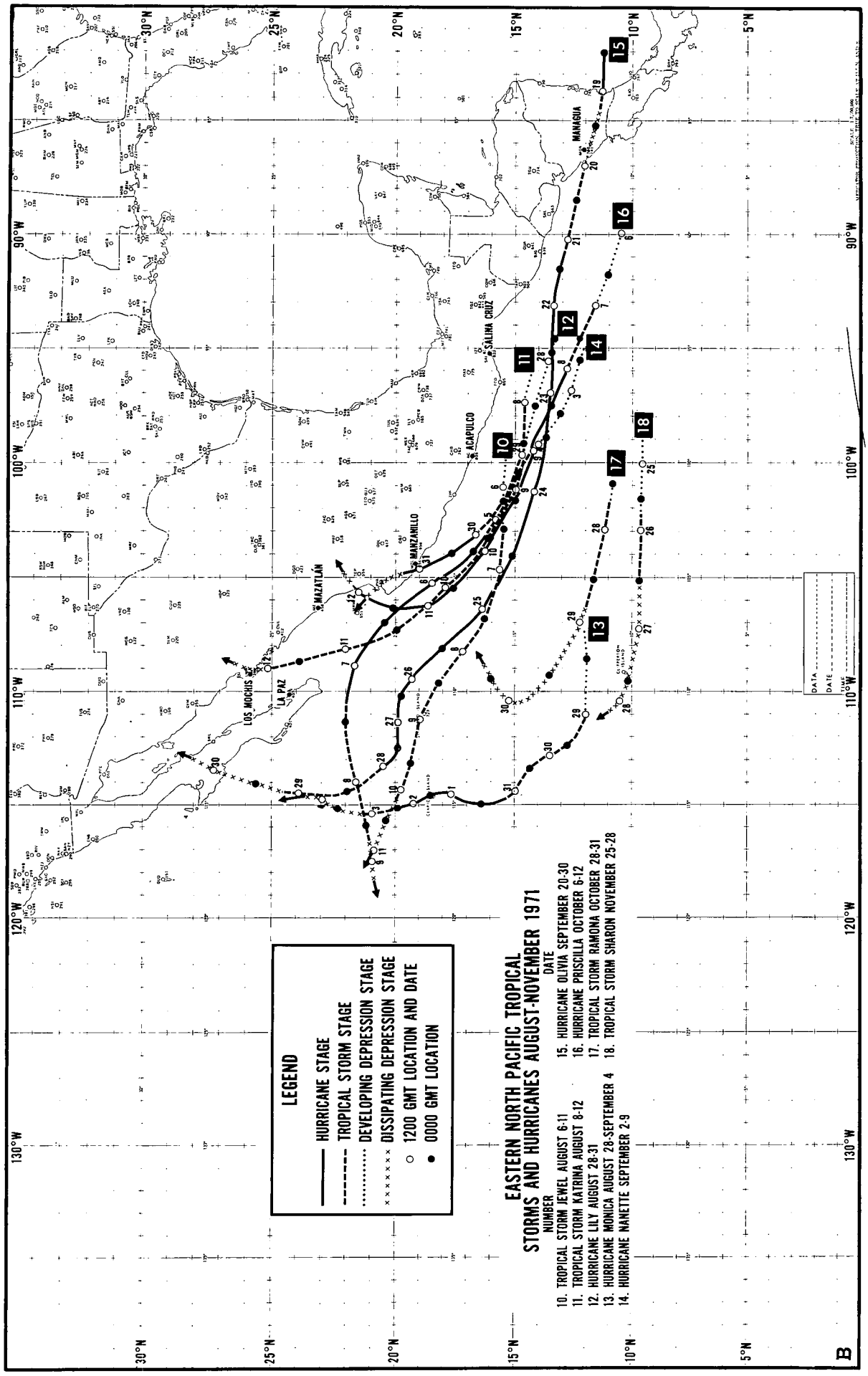

FIGURE 1.—Concluded.

TABLE 2.—*Monthly distribution of tropical storm and hurricane days* in the eastern Pacific in 1971*

Designation	May	June	July	Aug.	Sept.	Oct.	Nov.	Totals
Hurricane	3	2	14†	11	13	5	—	48
Tropical storms	1	2	19†	15†	6	3	1	47
Combined	4	4	33	26	19	8	1	95

*Each day with two storms is counted as 2 days; each day is counted according to the higher intensity of the cyclone involved.

†One additional tropical storm day and 2 hurricane days occurred in the central Pacific in July when Denise was west of 140°W, and 1 more tropical storm day was counted in August when the Central Pacific Hurricane Center was issuing advisories on Hilary.

estimates of many storms in seasons of the recent past. In this area of the Pacific, cyclones showing a circular eye with a closed wall cloud extending into the middle or upper troposphere on the reconnaissance radar have regularly been found to be of hurricane intensity, whether or not satellite pictures reveal the eye (e.g. hurricanes Nanette and Olivia this season). In the absence of direct reconnaissance observations, when radar information indicates the presence of a well-developed circular eye, the assignment of a category 3.5 classification under the NESS system seems to give a reasonable basis for maximum wind estimates.

All of the eastern Pacific storms and hurricanes of the 1971 season are believed to have been warm core from the beginning; there was early reconnaissance confirmation on most. Five hurricanes had winds of 100 kt or more; the wind speeds of some of the remaining seven may have reached 100 kt. There were reports from ships and reconnaissance aircraft of surface winds of 65 kt or more in all the hurricanes except Carlotta. The strongest winds reported in Carlotta by U.S. Air Force reconnaissance were 60 kt, so only tropical storm intensity was given in operational advisories. Carlotta was reclassified as having been a hurricane on July 3 and 4 on the basis of a post-season study of reconnaissance findings (see summary on Carlotta). Winds of 40 kt or greater were reported in four of the six tropical storms; there were no wind reports to confirm tropical storm intensity for Ramona and Sharon. The hurricane-force winds (Beaufort force 12) reported in tropical storm Katrina were attributed to a severe tropical line squall; for statistical purposes, this was considered a short duration wind. There was a reconnaissance report of 40-kt surface winds in tropical cyclone number 6 at a time when pictures indicated that rapid dissipation had begun; that cyclone was treated as a tropical depression.

2. PEAK PATTERN OF ACTIVITY

There was a marked peak of cyclone activity during July and early August. Two or more cyclones were active on 27 of 42 days of the period July 2 through August 12. On 5 days of the period, there were three active cyclones; on 3 days of the period, no activity was recorded. Nine of the season's 18 hurricanes and tropical storms occurred during this 42-day period. Seven of the nine started during July, the first six intensified in the same general area west of 105°W and then moved west-northwest or west. The seventh and eight cyclones of the series, hurricane Ilsa and tropical storm Jewel, were related to one another but differed from the preceding six in both structure and track. Ilsa and Jewel were quite large and loosely organized and seemed to depend upon feeder bands rather than an eyewall for accumulation of warm air in a central area 50 n.mi. or more in diameter. Tropical storm Katrina, which developed in the southeast quadrant of the broad circulation around Jewel, had a track conforming to the pattern prevailing during late August through mid-October. Katrina, a tightly wound mini-storm, was completely different in structure from Ilsa and Jewel.

The change in pattern of activity was not completed until after hurricanes Monica and Lily developed concurrently. Monica developed where the July series had formed but moved slowly north rather than west or west-northwest. Lily developed near the Gulf of Tehuantepec and moved on a gradually curving track, into Mexico near Manzanillo. The conditions affecting development and movement of Nanette, Olivia, and Priscilla were similar to those affecting Lily, though there were significant individual differences. These four hurricanes had much in common with the early season hurricanes Agatha and Bridget.

An eastern Pacific cell of the midtropospheric subtropical high-pressure belt aloft appeared to extend east at least to the longitude of Baja California while the July series of hurricanes was active. At other times during the season, development and steering appeared to be under the influence of a cell centered over or east of Mexico, with a flat col at the longitude of development of the July cyclones. The col was not persistent continuously. A short-wave ridge in the middle-latitude westerlies to the north filled the col to divert Nanette westward after she had started to recurve, and another ridge temporarily blocked the recurving of Olivia. Little support for the conclusions stated here as to location of High cells and col can be found in the mean circulation analyses. Because of the general lack of eastern Pacific upper air data for analysis, the pattern of hurricane development and movement may be a better index of the subtropical high-pressure belt in the midtroposphere than other data. This opinion is prevalent among hurricane forecasters dealing with eastern Pacific daily analyses.

Generally, the 1971 cyclones developed near the north edge of the intertropical convergence zone (ITCZ). Some appeared to have the ITCZ cloud band wound into the hurricane spiral as a feeder, as seen occasionally in previous years.

Seedlings marked by enhanced shower activity and a surface isallobaric system are known to cross the Central American isthmus from the Caribbean; a few were seen to develop into 1971 Pacific hurricanes (Frank 1971). Other, unobserved seedlings may have crossed the isthmus and initiated hurricanes. Hurricane Olivia was the regenerated Caribbean hurricane Irene, which weakened to depression intensity while crossing the relatively low

terrain of southern Nicaragua and promptly regenerated upon reaching the Pacific.

3. LIMITED DATA AND THEIR USE

Basic data limitations continued to be a serious problem. Aerial reconnaissance and satellites were again the principal sources of information. Data received for the 0600 and 1200 GMT maps rarely were sufficient to improve on extrapolated storm intensity and position. Even when ships were known to be in a storm area and requests for special ship reports were being broadcast, limited radio operator coverage usually meant no information. Synoptic and aviation reports from Mexican stations were relayed irregularly and those from Socorro Island, rarely. A few synoptic reports were received from Clipperton Island, French Polynesia, late in the season, the first in several years. No radiosonde or land-based radar information was available other than radiosonde reports from northern Mexico.

Automatic Picture Transmission pictures were available for direct reception at San Francisco, Calif., from the ESSA 8, ITOS 1, and NOAA 1 satellites at the beginning of the season but only from ESSA 8 after hurricane Bridget. NOAA 1 nighttime infrared pictures were the basis for reclassifying Bridget from tropical storm to hurricane intensity. These infrared pictures were not available later in the season. NESS regularly provided timely evaluations of data from ESSA 9, Applications Technology Satellite 1(ATS 1), and ATS 3 satellites. Movie loops from ATS 1 and ATS 3 were used for these evaluations. ATS 3 was nonfunctional for a few weeks at the peak of the hurricane season, but when it was functioning it did provide the first information of the day several times. The extensive tropical analysis program and ATS 3 movie loops from the National Hurricane Center (NHC), Miami, Fla., were sources of helpful suggestions from time to time.

During the 1971 season, no low-level satellite wind data were available at San Francisco for input to the surface streamline analysis. That analysis usually was adequate for a reasonable estimate of the temperature and moisture of the hurricane inflow, but lack of data frustrated most attempts to apply the Fujita equatorial anticyclone model (Fujita et al. 1969). A few cirrus-level winds were occasionally furnished by NESS for tropical areas. Upper air information rarely could be used to improve upon extrapolation for a storm track forecast, except when the National Meteorological Center (NMC) primitive-equation model forecast a middle-latitude trough into the subtropics. Upper air information pertinent to hurricane outflow usually was limited to that deduced from satellite pictures.

The U.S. Air Force 9th Weather Reconnaissance Wing provided daily reconnaissance on tropical storms and hurricanes and over areas where there was good reason to suspect storm development. Fixes were usually made twice daily on storms within 200 n.mi. of Baja California. This was ordinarily accomplished by one flight, with a 3- to 5-hr interval between fixes. A synoptic reconnaissance track was flown several times into the deep Tropics near 10°N, 98°W, when hurricanes were not in progress; in some cases, this reconnaissance provided early clues on storm development and generally helped to fill gaps in data-sparse areas.

Most of the flights were in WC–135 aircraft; some flights were made in WC–130 aircraft by the 55th Weather Reconnaissance Squadron. Other WC–130 flights were made from Panama by Atlantic hurricane hunters when Olivia and Priscilla were near the Central American coast southeast of Acapulco.

Both types of aircraft were well instrumented and equipped for dropsonde operations. Dropsondes were used regularly in the eye and along the periphery of storms. WC–130s obtained detailed information at 700 mb, including temperatures inside and outside the eye and Doppler winds. Most of the WC–135 flights penetrated to the hurricane eye at 300 mb. In some cases, WC–135 flights descended into the eye if there was no likelihood of dangerous or damaging turbulence and there was a need for low-level observation. In a few cases, penetration into the stronger hurricanes was blocked by unbroken wall clouds extending several thousand feet above 300 mb; in such cases, the reconnaissance crew reported radar indications and other information from the edge of the hurricane. We wish to thank all flight crew members who spent long hours in the air, remote from aviation support facilities, to secure the information. We especially thank the flight meteorologists, whose descriptions of hurricane activity are cited extensively.

4. CHRONICLE OF HURRICANES AND TROPICAL STORMS

Hurricane Agatha

Intertropical convection increased as waters south of Tehuantepec, Mexico, warmed up to about 30°C in mid-May. The presence of a low-pressure center in the equatorial trough became apparent early on May 21 when a ship encountered an east wind of 15 kt at 1200 GMT. During the following few hours, a time-lapse movie loop made from ATS 3 pictures revealed increasing circulation around a center at 12°N, 94°W. Agatha reached tropical storm intensity shortly after the NOAA 1 picture (fig. 2) was taken.

Two ships encountered 50-kt winds at 0600 GMT on May 22; this information fixed the center 190 n.mi. south-southwest of Salina Cruz, Mexico. Storm movement on the 21st and 22d was to the west-northwest about 10 kt on a track approximately parallel to the coast line. Hurricane intensity with 65-kt maximum winds was estimated from satellite pictures available at 1800 GMT on May 22. A reconnaissance radar fix was made at 2035 GMT on a 30-n.mi. diameter eye; a strong feeder band from the southwest was spiraling into the northeast side of the hurricane. The diameter of the circular eye was 15 n.mi. when seen by reconnaissance at 1740 GMT on May 23. Winds as strong as 70 kt were encountered at 500 mb, which suggested maximum sustained surface winds of

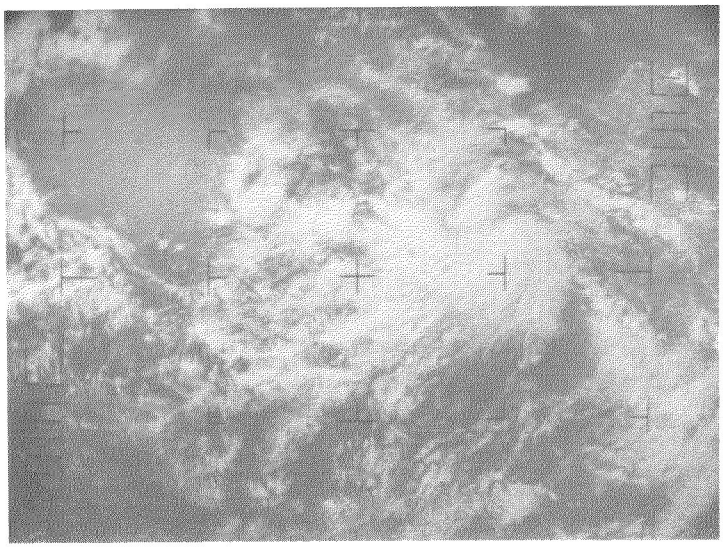

FIGURE 2.—NOAA 1 picture, orbit 2023, May 21, 1971, showing Agatha in near-tropical storm stage 500 n.mi. southeast of Acapulco, Mexico.

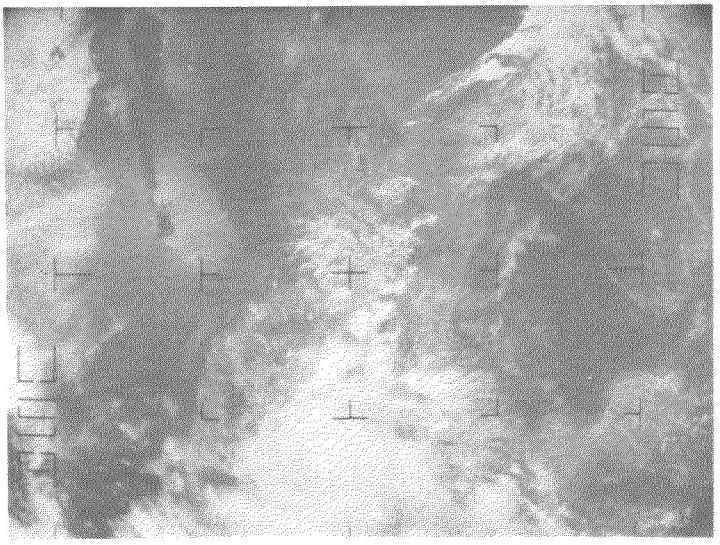

FIGURE 3.—NOAA 1 picture, orbit 2048, May 23, 1971, showing Agatha as a small, powerful young hurricane with eye 100 n.mi. southwest of Acapulco.

about 75–80 kt (Hawkins 1962). The 0°C eye temperature at 500 mb was 7° higher than that of the environment. Dropsonde sea-level pressure was read as 972 mb from a weak signal received through interference. The well-formed circular eye appeared to intensify, and to shrink in diameter by 2 or 3 n.mi. during the reconnaissance. There was an extensive cirrostratus shield over the entire hurricane area. The feeder band and cirrostratus outflow reported by reconnaissance can be seen in the NOAA 1 picture (fig. 3) made 3 hr later.

Maximum winds of 85 kt were encountered about daybreak on May 24 by the steamship *Torenia*, which also obtained a radar fix on the hurricane center. Movement onto land was confirmed by a reconnaissance radar fix at 18°N, 102.5°W, at 1707 GMT.

The eye of the hurricane passed within about 40 n.mi. of Zihuatanejo, Mexico; hourly winds at the local airport were reported at no more than 20 kt during the 6 hr prior to the landfall 75 n.mi. to the northwest.

The village of Playa Azul, 60 n.mi. up the coast from Zihuatanejo, was hard hit by the hurricane. Half of the homes were destroyed, and all of the banana harvest, 60 percent of the mango crop, and 15 percent of the coconut crop were lost.

Hurricane Bridget

Bridget was the worst hurricane to hit Mexico's beautiful resort city of Acapulco in more than 25 yr.

The first indication of possible development came on June 12 when there was a moderate push of Southern Hemisphere air against the Central American coast in the El Salvador area (Fujita et al. 1969). Southerly winds striking the coast were turning cyclonically, apparently in conformance with the contour of the terrain. Shower activity was widespread in Central America and offshore for about 2 days.

The flat low-pressure field began to deepen and move west-northwestward on June 14. At 0000 GMT on June 15, a ship reported 35-kt winds, 13-ft seas, and 1003.3-mb pressure, thus establishing tropical storm intensity. Strengthening continued as the storm moved west-northwestward at 10 kt across the Gulf of Tehuantepec, where water temperatures were reported as 28°–32°C. Hurricane intensity was inferred from a NOAA 1 nighttime infrared picture made at 0925 GMT on June 16. Intensity was confirmed by an 1800 GMT ship report of 75-kt winds, 30-ft seas, and 998-mb pressure.

The center of hurricane Bridget continued moving toward the west-northwest and accelerated to 14 kt. The storm moved past Acapulco some 30–40 n.mi. out to sea at 0200 GMT on June 17 (2000 LST on June 16). Winds started to increase and rain became intermittently heavy 3 hr earlier. At the height of the storm, 90-kt gusts were measured at Acapulco, Mexico, International Airport.

Wind in the Acapulco area damaged or destroyed many house roofs (especially palm thatch), outdoor advertising signs, and windows. The hurricane-force winds and violent seas on the bay sank 20 boats, plus the flagship of the Admiral of the Mexican Navy. Water rose above its normal level in the bay with flooding and high surf damaging waterfront and beach facilities. Runoff from torrential rains greatly exceeded the capacity of previously adequate drainage facilities that were in some cases clogged by wind-blown debris. Damage in the Acapulco area from wind and water was officially estimated at half a billion pesos, or 40 million U.S. dollars.

Bridget turned toward the northwest at about 1200 GMT on June 17 and went onto rough land some 85 n.mi. southeast of Manzanillo, Mexico, a few hours later. The hurricane winds subsided abruptly under the influence of friction over the mountains. A spiral cloud mass and a flat low-pressure system moved westward back onto the ocean near Manzanillo about 0600 GMT on June 18. The cloud system could still be identified south of Cape San Lucas on satellite pictures made 36 hr later, but there was no related surface circulation center. No information

is available on damage caused by Bridget outside the Acapulco area; the area where the storm went ashore is sparsely populated.

Hurricane Carlotta

Carlotta was not called a hurricane operationally, but a review of the July 3–4 information established that this storm was a hurricane for about 24 hr.

The initial depression first appeared on July 1 some 100 n.mi. east of Clipperton Island. A ship moving southeastward reported 10-kt northeast winds at 0000 GMT and 25-kt southeast winds at 0600 GMT, with showers and a 1009-mb pressure. An incipient circulation could be seen in the north edge of the intertropical cloudiness in an ESSA 8 picture taken at 1659 GMT on July 1. The ESSA 8 picture taken at 1750 GMT on July 2 was the basis for reclassifying this depression as a tropical storm.

On July 3, reconnaissance at 300 mb found a closed circular eye 15 n.mi. in diameter with a wall-cloud chimney producing a cirrostratus outflow to 90 n.mi. in all directions. Riehl (1959), in speaking to the 1958 Board of Review and Conference on Research Progress, stated ". . . and that which really distinguishes the tropical storm from the hurricane is the existence of the eye in itself." There have been instances when radar has detected an eye in a depression (Simpson and Pelissier 1971), but in those cases it can be assumed that there was no active wall-cloud chimney manifested by extensive cirrostratus outflow and requiring rapid surface inflow. At 300 mb, maximum winds of 45 kt were found at a point 15 n.mi. southwest of the center, and temperature rose 2° (to −30°C) when the eye was entered, which is consistent with the diagnosis of a young hurricane (Hawkins 1962). In the pictures from ESSA 8 and ESSA 9, Carlotta appears near the edge of the frames so detail was poor. Considering the presence of thick cirrostratus over the eye, we believe that even a picture made directly overhead might not have shown the fine distinction in shading made by a dimple in the cirrostratus top.

At 1800 GMT on July 4, aircraft reconnaissance reported 980-mb surface pressure in the eye and 58-kt maximum winds at 500 mb, indicating at least near-hurricane intensity (Fletcher 1955, Hawkins 1962). Temperature inside the eye at 500 mb was −2°C compared to −7°C outside it; the eye temperature at 300 mb had risen to −24°C, a 6° increase since the preceding day, and a stadium effect was noticeable when the flight entered the eye at 300 mb. Weakening had already begun at that time, as indicated by reduced cirrus production, by stratification of the cloud system (fig. 4), and by a break in the south side of the eyewall. Streamlines leading into the hurricane inflow originated over waters colder than 22°C on the north side of the wall.

Carlotta weakened rapidly after July 4. Central pressure had risen to 994 mb, and maximum winds at 500 mb had decreased to 48 kt by 1800 GMT the next day. Temperature in the eye at 500 mb had cooled 2° to −4°C, and the −7°C temperature in the environment was unchanged. Eyewall clouds in the south quadrant had dissipated, and

FIGURE 4.—ESSA 8 picture, orbit 11,688, July 4, 1971. Carlotta has begun to weaken from cool inflow while Denise is an intensifying young tropical storm 700 n.mi. to the east-southeast.

feeder bands were weak. Satellite pictures showed that stable stratocumulus decks north of the storm had spread under the increasingly stratified hurricane spiral bands.

Carlotta appeared as a dissipating depression on ESSA 8 satellite pictures at 1919 GMT on July 6. The cloud spiral could still be identified on pictures as late as July 8, but all surface circulation had disappeared by then.

Hurricane Denise

On July 2, the first signs of Denise appeared 750 n.mi. east of Carlotta at the time that Carlotta had intensified to tropical storm strength. Carlotta appeared to protect the developing Denise from cool inflow off relatively cold water to the north by diverting westward most of the cool air that started south.

The area of showers in the satellite pictures taken July 2 generated a weak low-pressure center with winds reported as high as 25 kt the next day. A tropical storm with estimated 45-kt winds was seen on ESSA 8 pictures of July 4 (fig. 4). Strengthening continued, and Denise was classified as a hurricane early on July 6 after confirmation by a U.S. Air Force reconnaissance of the developing eye at 1917 GMT on July 5. Strong wall clouds at the time of the radar fix extended to 40,000 ft in the east, south, and west quadrants, but were weak in the north. The July 6 reconnaissance flight, by a WC–135 aircraft at 300 mb, made a radar fix on a closed circular eye 25 n.mi. in diameter. Strong continuous wall clouds extending to above 30,000 ft prevented penetration.

Denise continued to intensify. A reconnaissance flight penetrated the eye at 700 mb at 1740 GMT on July 7, after approaching the east side of the wall cloud between feeder bands. Heavy rain and light turbulence were

experienced in the wall cloud for about 2 min before the flight entered the 40-n.mi. diameter eye. The wall clouds were well defined from 1,500 to 26,000 ft, at which point they merged into a cirrostratus overcast. A sea-level pressure of 963 mb was extrapolated from 700-mb measurements (height 2698 m, temperature 18°C). Maximum surface winds were estimated to be 80 kt on the basis of the appearance of the sea, the estimated surface pressure, and the 60-kt, 700-mb wind measured during penetration into the east quadrant. Concurrent ESSA 8 pictures revealed little detail in the central overcast area that was covered by amorphous cirrostratus.

Denise was still stronger on July 8. A reconnaissance flight penetrated the eyewall from the north at 700 mb, approaching through breaks in the feeder bands. Showers with light turbulence and flight-level winds up to 118 kt were found in the 5-n.mi. thick wall that extended to 38,000 ft. The 700-mb eye temperature had cooled to 13°C; warming at other levels had caused a decrease of surface pressure to a dropsonde-measured 951-mb value. The sea surface could be seen under edges of the eyewall; its appearance indicating surface winds of about 110 kt on the north side and 80 kt on the south side. The 118-kt flight-level wind encountered upon penetration is the basis for a conservative estimate of sustained surface winds up to 125 kt on unseen portions of the sea (Hawkins 1962). The eye was filled with cumulus and stratocumulus, with highest tops at 29,000 ft; there was scattered cirrus above 34,000 ft. The reconnaissance aircraft climbed to 36,000 ft to leave the eye.

The continued movement of Denise at low latitudes and the presence of Carlotta to the west-northwest through July 8 minimized inflow of air from cool water north of 20°N.

A radar fix was made at 1825 GMT on July 9 by a reconnaissance aircraft that did not penetrate the storm. Satellite pictures taken on the 9th indicated weakening, but reconnaissance on the 10th indicated that the weakening had been slight.

On July 10, a reconnaissance flight reported 700-mb winds of 100 kt 30 n.mi. north-northeast of the center and estimated 100-kt maximum surface winds to within a 25-n.mi. radius of the center. The sea surface was not visible, and no dropsonde measurements were made. The eyewall had begun to dissipate and was poorly defined on radar. The 700-mb temperature in the eye was 12°C, or 1° cooler than 2 days earlier. The temperature at 700 mb in the rain area had cooled 3°C during the same period, increasing the contrast by 2°. This increase in the hydrostatic contribution to the pressure gradient at that level, presumably from slightly cooler inflow, might be the basis for some interesting speculation. The disintegration of the wall clouds indicated that the means for concentrating energy in the core of the hurricane had about disappeared. Individual satellite pictures and a 2-hr movie loop of ATS 1 pictures supported the diagnosis of a trend toward weakening.

The following "Postflight Report" from the July 11 reconnaissance flight (Air Force Lark 07 Denise) told of continued weakening: "FIXED DENISE BY PENETRATION WITH WC130 AIRCRAFT AT 111804. STORM LOCATED 17DEGREES 13MINUTES N 144 DEGREES 12MINUTES W. MAX SFC WIND OBSERVED WEST QUAD AT 75KTS. CENTER IS BIG CIRCULAR 30NM ACROSS AND IS FILLING WITH STRATIFIED CLOUDS. NORTHWEST QUAD STILL HAS GOOD WALL CLOUD. BANDING STILL OBVIOUS AROUND CENTER BUT IS LOSING ITS ORGANIZATION. STORM IS WIDE OPEN EAST THROUGH SOUTHWEST. RADAR COVERAGE NOT FEASIBLE. DENISE IS DYING."

A July 12 reconnaissance flight found only 40-kt maximum surface winds in fixing the center of Denise at 17°19′N, 149°46′W at 1800 GMT. Another flight was made into the dissipating storm center at 0340 GMT on July 13 because of its proximity to the Hawaiian Islands. Winds were no more than 35 kt with the strongest in the northwest quadrants and light winds in the others. A final flight into remains of the storm at 16.5°N, 155.5°W at 1800 GMT on July 13 reported no surface winds in excess of 20 kt.

Tropical Storm Eleanor

Eleanor developed east of hurricane Denise on July 7 as hurricane Carlotta dissipated to the west-northwest. A shower area with cirrus outflow was photographed by satellite near 12°N, 107°W. A low-pressure circulation was suggested by a 20-kt southerly surface wind to its east.

Strengthening began early on July 8; the ESSA 8 picture led to an estimate of maximum winds about 40 kt. The new storm strengthened slightly during the following 24 hr, then began to weaken. A reconnaissance flight at 2030 GMT on July 9 found a poorly organized wall cloud around a circular eye 20 n.mi. in diameter. The ESSA 8 picture and surface streamlines indicated that stable air was entering the northern edge of the storm circulation.

A reconnaissance flight at 1750 GMT on July 10, reported no wall cloud and only short feeder bands in the north and east quadrants. Maximum surface winds were estimated at 40 kt, and the lowest pressure was 1009 mb. The next day, the storm was a dissipating depression with maximum winds of 30 kt moving toward the west-southwest.

Hurricane Francene

Francene developed from an area of enhanced shower activity and slight low-pressure circulation first seen near 12°N, 104°W on July 17. An ATS 3 movie loop made at the NHC shortly before 1800 GMT on July 18, indicated increasing circulation. Tropical storm strength was revealed July 19 at 0000 GMT by a ship report of 35-kt winds in the southwest quadrant. Rapid intensification to hurricane strength took place during the following night; reconnaissance found 100-kt surface winds in the northwest quadrant of the 25-n.mi. diameter eye at 1800 GMT. A concurrent ESSA 8 picture depicted profuse cirrus outflow over the center and an extensive stratocumulus

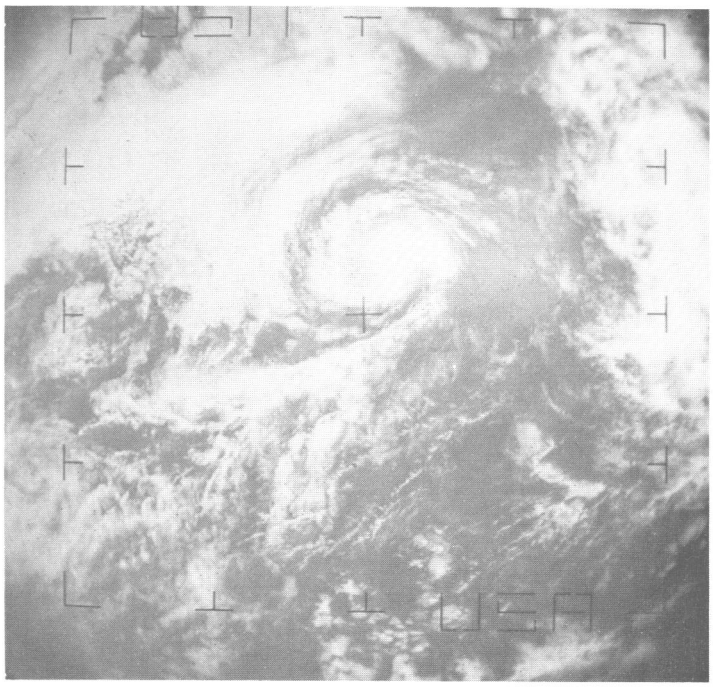

FIGURE 5.—ESSA 8 picture, orbit 11,889, July 20, 1971. Francene has weakened due to cool inflow.

layer, indicating cool surface air, about 300 n.mi. northwest of the center.

The new hurricane promptly provided for its own weakening. Its expanding and increasing circulation and northwestward movement brought cool surface air into the spiral inflow.

By 1800 GMT on July 20, Francene had weakened to tropical storm intensity with 60-kt maximum winds and a central pressure of 991 mb; there was a wall cloud only in the northwest quadrant of the 35-n.mi. diameter eye. The reconnaissance flight also found an eye temperature of 9°C and an environment temperature of 6°C at 700 mb. The deterioration of the storm's feeder bands under the influence of cool inflow could be seen in the concurrent ESSA 8 picture (fig. 5).

Twenty-four hr later, maximum surface winds had decreased to 40 kt, minimum pressure had risen to 1005 mb, eye temperature at 700 mb had risen to 11°C, and the environment had warmed to 3°C. Wall clouds had dissipated completely, and there were few buildups. The 700-mb center appeared to be 20 n.mi. east of the surface center. The concurrent ESSA 8 picture showed a sheet of trade-wind stratocumulus less than 200 n.mi. from the center around the north and northwest sides.

Slight regeneration was noted by a reconnaissance flight into the storm center at 1918 GMT on July 22. Maximum surface winds of 45 kt and minimum pressure of 995 mb were reported. Temperature at 700 mb in the 45-n.mi. diameter storm center had risen to 15°C and the environment had warmed to 11°C. A weak section of eyewall had reappeared in the northwest quadrant, and there were weak feeder bands to the east and northeast of the center. The evident reversal of the dissipation trend may have been caused by a reduction in the rate of cool inflow that permitted resumption of convection in the storm center.

The slight revival of Francene on July 22 was only temporary. The ESSA 8 picture on the 23d clearly indicated weakening. A cloud spiral was still visible on pictures taken on the 24th, but the surface circulation had about disappeared.

Tropical Storm Georgette

The depression that became tropical storm Georgette appeared at about 13° longitude east of the weakening Francene on July 22. The ESSA 8 picture indicated an incipient circulation in an area of showers. A reconnaissance flight found a loosely organized tropical storm on July 23. The 45-n.mi. diameter center had no wall cloud. The 700-mb temperature was 13°C and the environment temperature was 11°C. Flight level (700-mb) maximum winds were 55 kt some 60 n.mi. north-northwest of the center, and maximum surface winds of 45 kt were estimated at the partially observed sea surface.

By 1750 GMT on July 24, a partial wall cloud had developed in the north semicircle of the storm and feeder bands were wrapped around the north side. Temperature in the eye at 700 mb was still 13°C, but the environment had cooled to 9°C. The maximum 700-mb wind measured was 50 kt; a minimum sea-level pressure of 991 mb was measured by dropsonde. An ESSA 8 picture taken at about the same time as the reconnaissance showed that the storm cloud system was joined on the north and northwest by the trade wind stratocumulus sheet and its cool surface air.

Ships passing 100 to 150 n.mi. north of the center of Georgette during the following night reported winds of 30–35 kt and sea-surface temperatures of 21°–23°C. The ESSA 8 satellite picture taken at 1818 GMT on July 25, showed that the cloud system had become mostly layered with one weak feeder band some 150 n.mi. from the center to the east and 100 n.mi. to the north. Possible cool inflow was suggested by the proximity of trade-wind stratocumulus.

On July 26, a reconnaissance flight found a stratiform cloud system having tops at 17,000 ft that gave no radar return and had the feathered edges characteristic of evaporating clouds. Light rain was encountered briefly at 700 mb during penetration to the 50-n.mi. diameter center, and flight level maximum winds of 55 kt were measured. Temperature in the center was 12°C, only 1° warmer than outside. Surface winds as strong as 45 kt were seen in the northeast quadrant. The flight meteorologist reported that the storm appeared to be weakening rapidly.

That trend was confirmed by reconnaissance the next day. Cloudiness and winds in the area of the dissipating Georgette gave no indication of storm activity.

Hurricane Hilary

Hilary was the last storm of the season to attain tropical storm intensity west of 105°W. The slow westward progress of this cyclone between 110° and 125°W gave

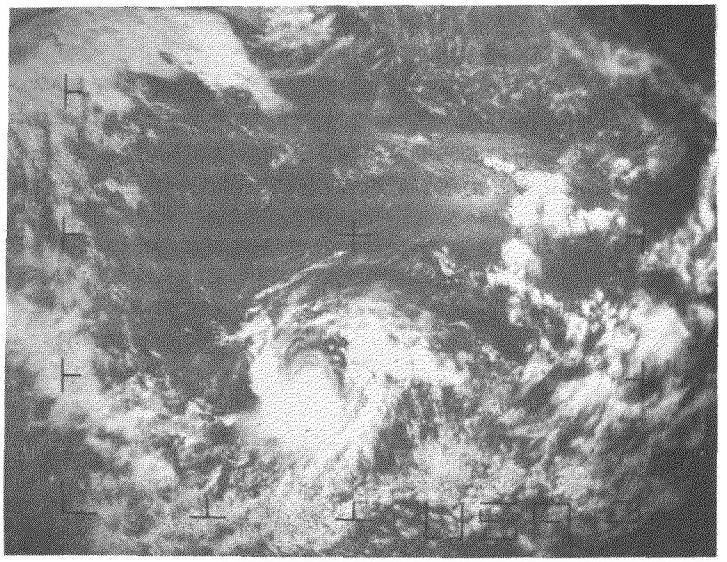

FIGURE 6.—ESSA 8 picture, orbit 11,964, July 26, 1971. Hilary is a young tropical storm 100 n.mi. west of Clipperton Island, French Polynesia.

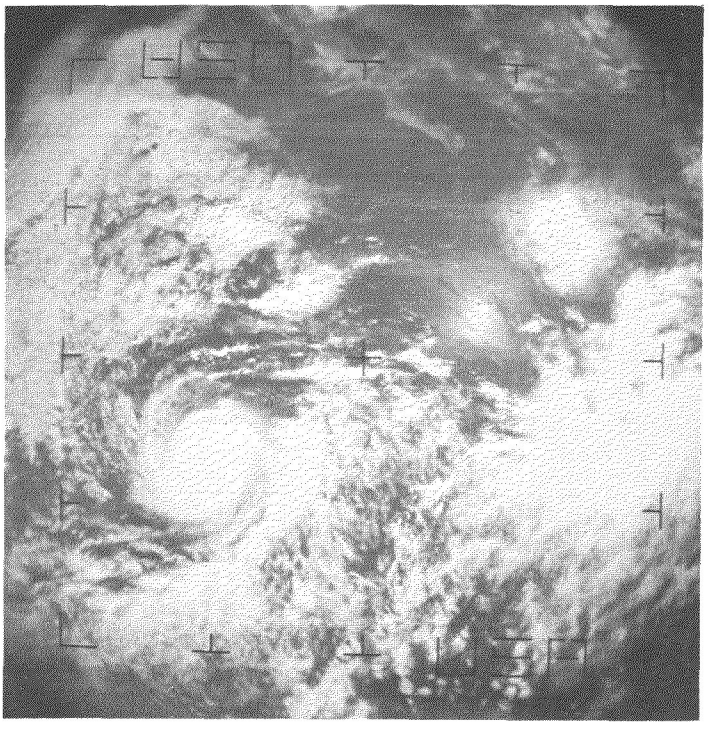

FIGURE 7.—ESSA 8 picture, orbit 12,027, July 31, 1971. Hurricane Hilary is southwest of the picture center while Ilsa is organizing near the east edge of the picture, some 300 n.mi. south of Manzanillo, Mexico.

a hint as to the weakening of the subtropical high pressure belt to the north, and an attendant impending change in the pattern of storm activity.

Cyclonic curvature of cumulonimbus bands in the intertropical cloudiness was seen near Clipperton Island in a July 25 ESSA 9 picture. The circulation of Hilary organized rapidly as Georgette dissipated 1,000 n.mi. to the northwest. A young tropical storm was seen in the ESSA 8 pictures taken on July 26 (fig. 6); it had intensified considerably when photographed by satellite on July 27. The picture taken on the 27th showed extensive thick cirrus outflow completely obscuring a 150-n.mi. diameter central area and partially obscuring outer banding. A reconnaissance aircraft flying at 300 mb penetrated the eye at 1708 GMT on July 27. During the flight through the wall clouds, moderate turbulence, icing, and heavy showers were encountered. The eye temperature at 300 mb was 3°C higher than the environment; the wall cloud was open in a 30° sector in the south. Heavy cirrostratus below flight level obscured the sea in the eye, thus preventing estimation of surface winds.

A reconnaissance flight at 700 mb at about 1730 GMT on July 28 found a tightly wound and symmetrical young hurricane. Maximum winds measured at the 700-mb flight level were 75 kt from the southeast. Maximum sustained surface winds of 80 kt were estimated from the 700-mb winds and a 964-mb surface pressure measured by dropsonde. Temperature was 17°C in the 13-n.mi. diameter circular eye, and 10°C in the wall cloud. Quite rapid changes in pressure and temperature were noted during the flight through the wall cloud. The center was filled with layered clouds obscuring the surface, but there was an excellent stadium effect in the 35,000-ft wall cloud and a small hole in the cirrostratus over the eye. The 50-kt flight-level winds extended to 70 n.mi. north of the center.

A radar fix showed a 20-n.mi. diameter circular eye 24 hr later, but the tall, unbroken wall clouds could not be penetrated safely by the WC–135 aircraft. Winds at the 700-mb flight level were measured as strong as 70 kt some 40 n.mi. west-northwest of the center. Well-formed feeder bands were seen encircling the storm and converging into the north and southwest parts of the wall cloud, which was strongest on the south side. The concurrent ESSA 8 picture showed that the feeder bands had lost connection with the intertropical band of cloudiness.

A reconnaissance flight found a break on the east side of the eyewall and entered at 700 mb at 1800 GMT on July 30. Minimum surface pressure was 981 mb and the maximum flight level wind was 68 kt. The eye was elliptical, with 15- and 25-n.mi. axes. Moderate turbulence and moderate rime icing was encountered in feeder bands at 27,000 ft. Satellite pictures still showed the feeder bands separated from the intertropical cloudiness; the presence of stable air about 300 n.mi. northwest of the center was indicated by a stratocumulus sheet.

Hilary was still a vigorous hurricane on July 31, though the height of the cloud system had decreased. A reconnaissance flight at 300 mb found a flat top to the cloud system at 29,000 ft, but the closed wall cloud around a 25-n.mi. diameter circular eye gave a good radar return. A central pressure of 964 mb was measured by dropsonde; this pressure was 12 mb lower than the day before. Winds at the 300-mb flight level measured no stronger than 15 kt, and eye temperature at that level was only 2°C higher than over the eye wall. Figure 7 is the ESSA 8 picture for this date.

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The direction of hurricane motion became erratic early on July 31, with a turn to the west southwest followed by a turn to northwest the next day. The latter turn brought the hurricane closer to cold water and stable air. On August 1, winds as strong as 75 kt were estimated from reconnaissance and satellite information. Wind speeds decreased steadily thereafter, and had diminished to 50 kt when measured by a reconnaissance flight on August 3. Eye temperature at 700 mb was 12°C, temperature outside the eye was 9°C, and cloudiness was predominantly stratified with no cumulonimbus. Hilary was barely a tropical storm, with 35-kt maximum winds, when fixed at 19.6°N, 138.5°W at 1705 GMT on August 5. Dissipation occurred west of 140°W during the next 2 days.

Hurricane Ilsa

An ESSA 8 picutre at 1649 GMT on July 30 revealed the first strong evidence of the beginnings of hurricane Ilsa, showing arc-shaped lines of cumulonimbus around a loose center near 12°N, 97.5°W. The intertropical cloudiness was quite extensive to the west and south. Development was noted in the ESSA 8 picture taken on July 31 (fig. 7); the circulation was a loosely organized center into which many partial bands of cumulonimbus were spiraling. There were 30-kt southeast winds in the northeast quandrant about 300 n.mi. from the center.

At 0300 GMT on August 1, the ship *Irish Elm* (EIWT), moving west at 20 kt about 90 n.mi. north of the center, reported 20-kt winds and a 1005.5-mb pressure. The ship encountered rapidly deteriorating weather. By 0600 GMT the easterly winds had increased to 50 kt; by 0900 GMT, the winds reached 60 kt. The ship turned north when the wind increased to 50 kt but fought winds at least that strong for more than 12 hr. Reports from the *Irish Elm* were a principal basis for reclassifying Ilsa as a hurricane.

The ESSA 8 picture on August 1 showed a heavy cirrus outflow obscuring inner banding over the center of the hurricane. Heavy bands of cumulonimbus wrapped around the west side were separated from the central overcast by a concentric break about 25 n.mi. wide.

Ilsa is thought to have reached peak intensity on August 2 when on first inspection ESSA 8 pictures seemed to show a round eye 20 or 25 n.mi. in diameter (fig. 8). A closer look led to the conclusion that there was no cumulonimbus wall cloud chimney where it would normally be expected.

The warm core of the hurricane was apparently quite broad, and the structure of the system generally had more in common with a tropical storm than with the classical hurricane (Riehl 1959). The warm center seemed to be sustained by a broad spiral band of very heavy cumulonimbus with its inner boundary at 40–60 n.mi. from the apparent eye on the east side and less active convection and less vertical development on the west and south sides where the band was nearer the center.

No observations of wind speed were made in Ilsa on August 2, but the satellite pictures, the reports from the *Irish Elm* on August 1, and the reports from U.S. Air Force reconnaissance on August 3, when considered together, support the conclusion that Ilsa was a potent hurricane. There were ship reports from the north side, 25–50 n.mi. outside the heavy spiral band; 25- to 30-kt winds, and very rough seas were reported.

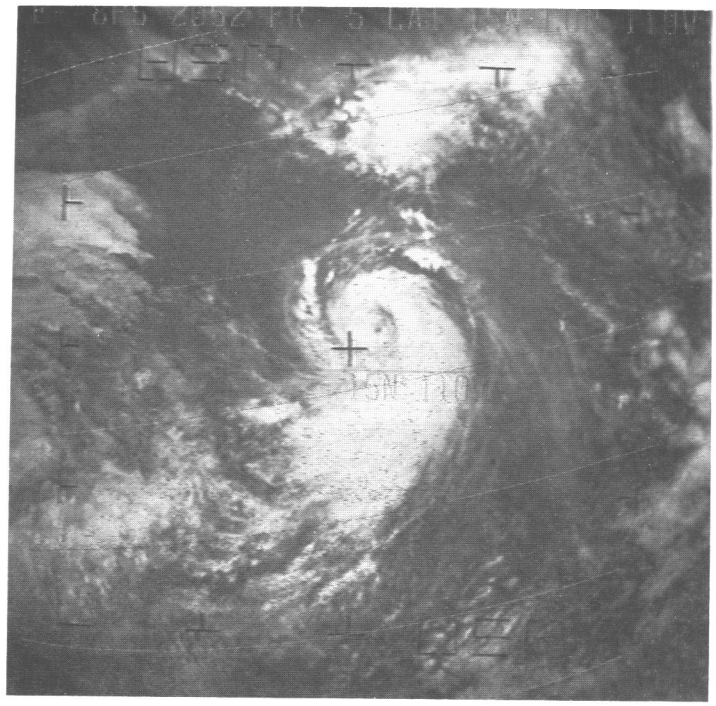

FIGURE 8.—ESSA 8 picture, orbit 12,052, Aug. 2, 1971, of hurricane Ilsa with main chimney of rising air in the heavy spiral band east and north of center.

A reconnaissance flight at 2223 GMT on August 3, reported a broad center, 50–60 n.mi. in diameter, and 65-kt surface winds visible on the sea surface just inside the wall cloud on the west side. The east semicircle of the broad eye was open with seven-eighths coverage of stratocumulus in the eye. Lowest pressure was estimated at 978 mb; the dropsonde signal faded at 840 mb. Temperature at 700 mb was 13°C in the eye and 8°C outside the eye. Ilsa appeared on the east edge of ESSA 8 pictures, so detail was limited, but overall appearance suggested a somewhat weaker storm than on August 2.

Satellite pictures on August 4 and 5 showed that the storm was slowly weakening. Reconnaissance flights found progressively less evidence of convection to support the storm but also noted surface winds as strong as 60 kt on both days. Minimum pressure was 986 mb on the 4th, and 988 mb at 1637 GMT and 996 mb at 2103 GMT, respectively, on the 5th. Temperature contrast between the storm center and the environment at 700 mb had decreased to only 1°C by the 4th.

Ilsa dissipated on August 6; the reconnaissance flight could find no signs of pressure gradients in searching the stratified cloud mass remaining near 23°N, 122°W. Dissipation probably was caused by the inflow of cool, stable air from the relatively cold water west of Baja California; such inflow was evident in the surface streamline analysis from August 3 on.

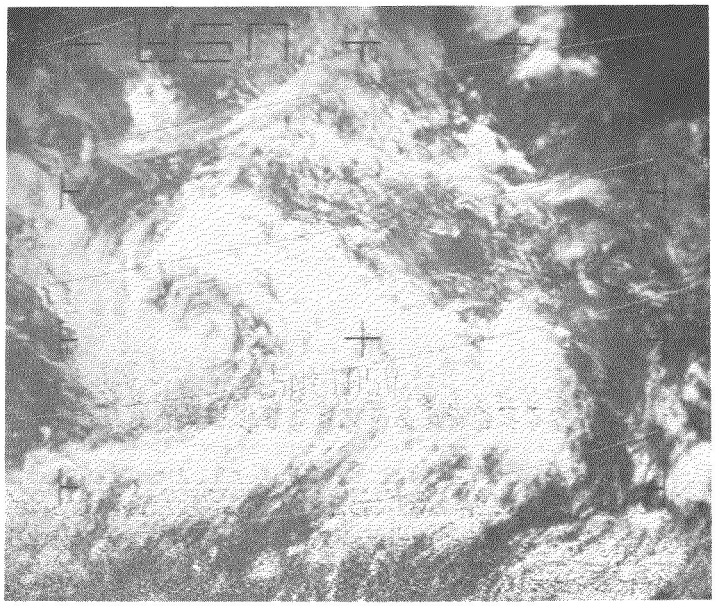

FIGURE 9.—ESSA 8 picture, orbit 12,127, Aug. 8, 1971. Jewel is a large, loosely organized tropical storm centered 300 n.mi. south of Cape San Lucas, Mexico. Strongest winds are more than 100 n.mi. from center.

Tropical Storm Jewel

The conditions that prevented hurricane Ilsa from developing a small eye with a complete wall cloud seem to have been operating even more effectively as tropical storm Jewel developed.

The first sign of the initial disturbance came in a report of 20-kt southeast winds from the *President Jackson* (KFCT) near 15.5°N, 95.5°W at 1800 GMT on August 5. The winds increased to 30 kt from the east-southeast during the next 6 hr, as the ship moved west-northwestward at 25 kt. Tropical storm intensity was shown 24 hr later by a report from the ship *Auralis* (HOOJ) of Beaufort force 7–8 winds, heavy rain squalls, 1007-mb pressure and falling, a very rough sea, and an 85°F water temperature. The ship report and a concurrent ESSA 8 picture placed the storm center near 15.5°N, 102.0°W.

A 300-mb reconnaissance flight at 2045 GMT on August 7 found a poorly defined eye with the partial wall cloud open to the southeast. Lowest surface pressure was 1000 mb, and the 300-mb temperature in the eye was 2°C higher than that outside. ESSA 8 pictures showed that Jewel covered a large area with loosely organized spiral bands. The strongest wind measured by a ship during the storm's lifetime was the 45 kt by the *Ocean Prima* (5MTR) at a location 150 n.mi. northeast of the center at 1800 GMT on August 7.

On August 8, minimum sea-level pressure had decreased to 993 mb; at 700 mb the temperature in the eye was 16°C, but 11°C in the immediate environment and 7°C (by dropsonde) 140 n.mi. to the northwest. The storm, with no sign of an eyewall, apparently was sustained primarily by a 200-n.mi. wide band of convectively generated clouds extending from the ITCZ. That band was wrapped around the east semicircle of the storm beyond 100–150 n.mi. from the center (fig. 9). There were lesser bands of apparent cumulonibus nearer the center, but most of the inner cloud spiral was composed of cumulus and stratocumulus with tops at 6,000 ft, except at 4,000 ft nearest the middle. A reconnaissance flight found no 700-mb winds stronger than 30 kt in the vicinity of the storm center. The structure of the storm, as determined from the satellite picture and reconnaissance observations, seems to justify a conclusion that the strongest winds in the storm were in the east semicircle more than 100 n.mi. from the center on August 8 and probably on the preceding and succeeding days.

Storm organization diminished during the next 24 hr. The reconnaissance aircraft descended to 1,200 ft at 1800 GMT on August 9 to observe the central area of the storm to a radius of 50 n.mi. Only light variable surface winds and a minimum sea-level pressure of 1002 mb were found. All temperature contrast between the center and environment had disappeared at the 700-mb level. The strongest surface winds observed by reconnaissance were 25 kt about 60 n.mi. northwest of the center.

Satellite pictures showed a conspicuous spiral structure in the remaining stratified clouds through August 12 (fig. 10), but surface circulation was slight after the 9th.

Tropical Storm Katrina

Tropical storm Katrina was an extraordinarily small, tight storm. There is reason to believe that that storm may have reached hurricane intensity for a time because a ship reported hurricane-force winds. In its early stages, Katrina apparently had the magnitude of a tornado cyclone, similar to that of the ministorm reported by Baum (1970). In its later stages, Katrina was smaller than hurricane Rebecca of 1968 (Denney 1969) in which the radius of gale winds was about 40 n.mi., and winds close to the eyewall were near 100 kt. The various sizes of hurricanes and ministorms seen in the eastern Pacific in recent years suggest that the size spectrum of cyclones with eyewall chimneys is continuous, with gale-wind area ranging in size from the 15-n.mi. diameter of a ministorm to more than 150 n.mi. in diameter in a large, mature hurricane. Any attempt to distinguish the ministorm from the hurricane would require an arbitrary definition by size. The dangers from the ministorms such as Katrina seem to argue against attempting such an arbitrary definition. The difficulty of following such a small system might argue for an arbitrary size definition; however, it might better be considered a challenge to the improving skill and technology of applied meteorology.

Continuity for Katrina's location and intensity before 0400 GMT on August 10 is largely hypothetical. Her small size was such that she could easily escape detection, even in the heavily traveled shipping lanes off the Mexican coast. The *Ocean Prima* (5MTR) is thought to have had an encounter with the developing Katrina at 1800 GMT on August 8. The ship at that time reported 35-kt southeast winds and a 4-mb pressure rise in 3 hr while moving south-

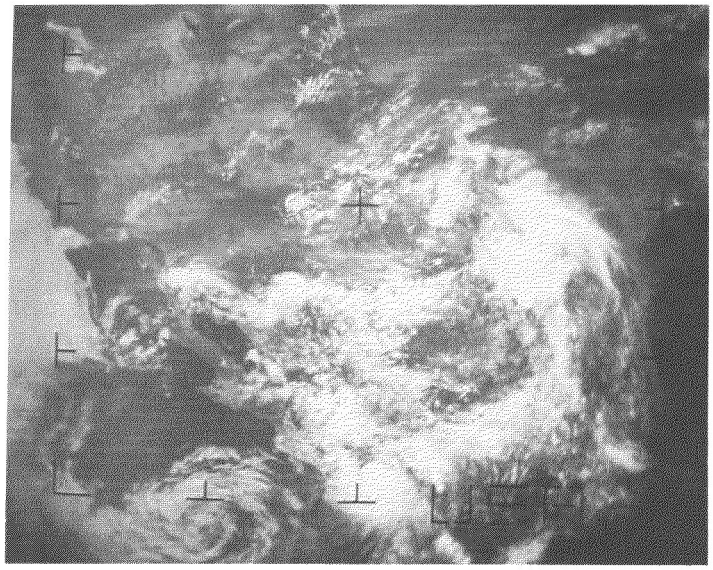

FIGURE. 10.—ESSA 8 picture, orbit 12,165, Aug. 11, 1971. Katrina is a ministorm with near-hurricane intensity in mouth of Gulf of California. Cloud spiral left over from tropical storm Jewel is centered 600 n.mi. to the west-southwest.

eastward at 20 kt. About 24 hr later, a possible ministorm was suggested by the appearance in the satellite photograph of an oval-shaped cloud mass less than 60 mi in diameter, about 250 n.mi. to the west of where the *Ocean Prima* reported the 35-kt winds. That cloud mass ordinarily would have been considered to be just a large thunderstorm system in the north edge of the intertropical band of cloudiness; but, because of the ship encounter and the satellite photograph, it was considered a possible location for Katrina in its early stages.

At 0542 GMT on August 10, the following report was received: "WARNING ELFW IN POSITION 1640N 10300W OFF CAPE TELMO COURSE 115 PASSED THROUGH SEVERE TROPICAL LINE SQUALL AT 0400GMT WITH HURRICANE FORCE TWELVE WINDS AND ZERO VISIBILITY AT FRONT WITH FRONT PASSING NE TO SW AND MOVING NW DIRECTION." (signed) ELFW/*Nego Enterprise*. The ship master's appraisal of this storm as a squall was perhaps partly influenced by warnings of squally conditions being broadcast for that area. In turn, his appraisal reinforced the earlier forecaster evaluation, though the strength of the wind was extraordinary for a simple squall. On August 10, satellite pictures received at San Francisco and at NESS did not show a tropical storm of conventional appearance; however, picture clarity was not the best. A cloud formation near 18.5°N, 106.3°W in the ESSA 8 picture was suspected of being a small tropical storm because of the *Nego Enterprise* report. It was shortly confirmed as just that.

At 2100 GMT on August 10, another ship reported estimated 40-kt east-southeast winds, with a pressure of 1010 mb falling at a rate of 5 mb in the past 3 hr, as the ship moved southeastward at 15 kt. The direction of seas at the ship was chaotic, their heights were 13 ft, and swells from the southeast were running 19 ft. Three hr later and 24 n.mi. to the west, a third ship reported estimated 52-kt southerly winds, pressure 1007.5 mb, and 1 mb/3 hr "check" tendency as the ship moved southeastward at 15 kt.

Katrina moved northward toward Los Mochis on the Mexican mainland, and weakened. The strongest winds reported at Los Mochis were about 25 kt from the east, some 24 hr after the August 11 picture (fig. 10). The weakening presumably was caused by dynamic instability resulting from strong anticyclonic shear beyond the eyewall winds (Simpson 1970).

The weakened storm caused up to 9 in. of rain in the Los Mochis area during the night of August 11–12, and heavy showers associated with the moist tropical air mass were prevalent for the next 5 days. Water rose to the top of railroad embankments on the fertile flood plain. The floods there and in the nearby hills destroyed 20 homes, sections of roads and railroads, three bridges, and a railroad trestle. Crops were ruined and 70 homes and five bridges were damaged.

Hurricane Lily

Numerous heavy showers occurred in the Gulf of Tehuantepec area on August 27. The ESSA 8 picture taken at 1639 GMT on August 28 showed the showers organized around a cyclonic circulation center at 13.7°N, 96.4°W. The circulation intensified steadily, became a tropical storm on the 29th, and a hurricane 2 days after first being seen in the satellite picture.

The ESSA 8 picture taken at 1730 GMT on August 29 indicated tropical storm intensity; the storm appeared on the right (east) edge of the picture. There was profuse cirrus outflow, with a perfectly semicircular contour around the north side of the head of a comma-shaped cloud mass 2° of latitude in diameter. The storm was classified "C Plus" (Anderson et al. 1969) from ESSA 9 pictures taken 4 hr later; no eye was visible.

On August 30, heavy anticyclonic cirrus outflow and a spiral organization appeared in the 1626 GMT ESSA 8 picture (fig. 11). The tall cumulonimbi of hurricane spiral bands blocked penetration by U.S. Air Force reconnaissance at 1700 GMT. The reconnaissance observer could see a 35-n.mi. diameter eye at 17.2°N, 103.8°W on the radar screen. The storm was rated "Category 2, diameter 2.5" (i.e., 60 kt) from the ESSA 9 picture.

Hurricane Lily moved toward the coast of the Mexican mainland at about a 30° angle. This was not anticipated in advisories partly because of difficulties in communicating the radar position determined by reconnaissance. Several ships were caught in hurricane winds and seas while trying to pass between the coast and the hurricane.

The SS *Turrialba* (GGCU) was in the eye of the hurricane at 1200 GMT on August 31; sea-level pressure was near 980 mb. The Third Officer reported that numerous tropical birds, terrified and exhausted by the storm, were taken on board the vessel. The ship had to maneuver to avoid other ships while in the hurricane eye.

The eye of hurricane Lily moved onto Mexico an estimated 30 n.mi. northwest of Manzanillo at about

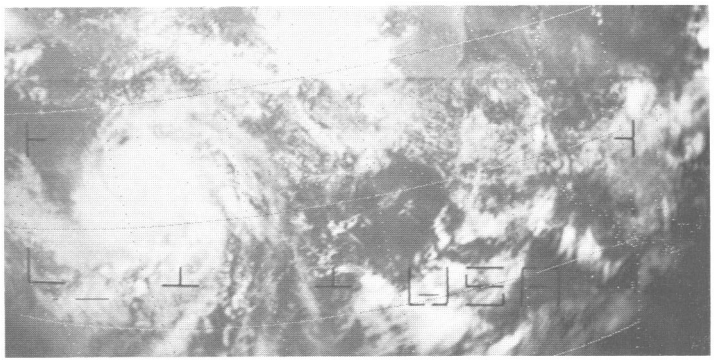

FIGURE 11.—ESSA 8 picture, orbit 12,403, Aug. 30, 1971. Lily is a young hurricane centered 140 n.mi. south-southeast of Manzanillo, Mexico.

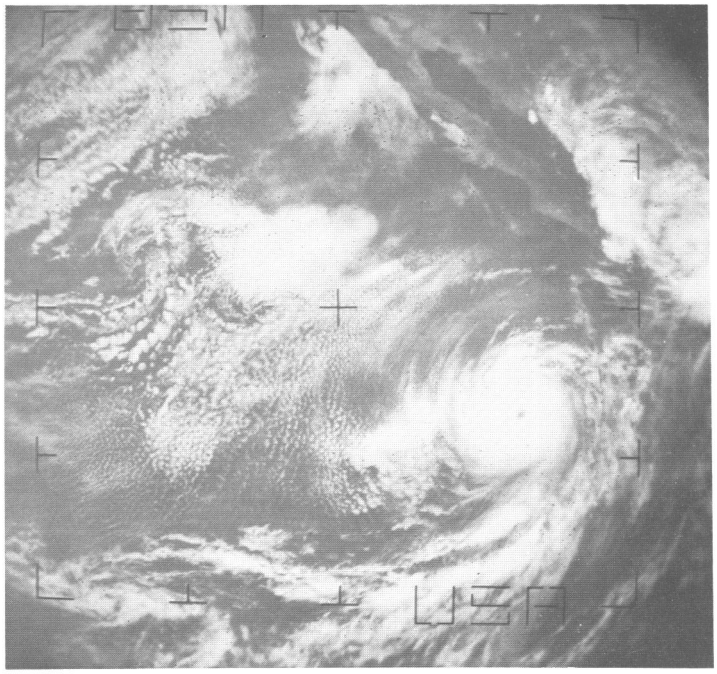

FIGURE 12.—ESSA 8 picture, orbit 12,429, Sept. 1, 1971. Monica was investigated by a U.S. Air Force reconnaissance flight at picture time and was described as the strongest hurricane ever seen in the area.

1500 GMT on August 31. An Associated Press dispatch from Puerto Vallarta reported the drowning of nine people when a boat capsized off a nearby beach in the high seas generated by the hurricane. The report mentioned a known death toll of 12 in Mexico but did not mention damage.

Hurricane Monica

Monica began to develop on August 28 about 150 n.mi. northeast of Clipperton Island concurrent with the beginnings of Lily south of Tehuantepec. The developing Monica followed a track parallel to Lily's on August 28–31, but moved only about two-thirds as fast. Monica also developed more slowly than Lily until shortly before Lily moved onto land and dissipated on August 31. On the satellite pictures taken August 29 and 30, Monica had the appearance of a tropical storm.

An abrupt strengthening to hurricane intensity took place August 31 as Lily was advancing toward the Mexican Coast 600 n.mi. to the east-northeast. Hurricane strength was clearly evident from a reconnaissance flight radar fix at 2255 GMT on August 31. The wall around the 12-n.mi. diameter circular eye was solid up to 30,000 ft, and there were feeder bands up to 35,000 ft within a radius of 200 n.mi. in all directions. The storm was rated "Category 2, diameter 4"—65 kt (Anderson et al. 1969) from the ESSA 9 picture.

A reconnaissance flight made a radar fix at 1719 GMT on September 1, and reported circling the hurricane completely 70–90 n.mi. from the center without finding an opening for penetration. The flight meteorologist described Monica as the most intense hurricane he had ever seen in that area. Winds up to 62 kt were measured at 700 mb, 78 n.mi. east-southeast of the center. The eye had expanded from 12 to 50 n.mi. in diameter.

The ESSA 8 picture taken at 1809 GMT (fig. 12) and the ESSA 9 picture, 2224 GMT on September 1, showed a clearly visible eye; the storm was rated "Category 3.5, diameter 4" (i.e., 90 kt) on each of the pictures. Stable inflow was suggested by stratocumulus clouds on the west fringe of the hurricane about 300 n.mi. from the center. Water temperature under the eye was about 28°C but was colder than 22°C beyond about 300 n.mi. to the north and northwest.

Monica was considerably weaker on September 2. Stable air from the stratocumulus area to the west and northwest had spread through the southwestern quadrant when the ESSA 8 picture was made at 1705 GMT, and the cloud spiral had become stratified and begun to evaporate. The weakening was documented through two reconnaissance fixes at 1624 and 1955 GMT. On the first fix of the 40-n.mi. diameter eye, maximum surface winds of 75 kt were seen 35 n.mi. east-northeast of the center, and a minimum surface pressure of 995 mb was indicated by a questionable dropsonde. An eyewall present on the west side only was poorly defined on radar. Generally, the cloud system seemed to be flattening out with a stratocumulus layer extending into the center. Visible weakening and a decrease in radar return were evident during the 4 hr that Monica was under observation. Surface winds were estimated no stronger than 65 kt on the second fix when maximum winds at 700 mb were 55 kt. The 700-mb eye temperature was 16°C or 3° warmer than outside. Dynamic processes sustaining the storm had ended, and the warm core was being mixed into the environment.

Dissipation was observed by means of reconnaissance and satellite photography during the following 2 days. Two reconnaissance flights, at 1550 and 1950 GMT on September 3, reported central pressure rising from 1002 to 1005 mb and maximum surface winds decreasing from 40 to 35 kt. There were no clouds above 12,000 ft in the central area of the storm nor was there a wall cloud. The few light rain showers in the north quadrant of the storm out to

60 n.mi. from the center gave no significant radar return. The 700-mb center temperature of 12°C was still 3° warmer than the environment. Satellite pictures taken September 3 showed a larger cloud spiral than did those of September 5.

Maximum surface winds were 25 kt and central pressure, 1005 mb when the remains of Monica were studied by reconnaissance at 1609 GMT on September 4. There was no precipitation from the stratocumulus and altostratus clouds, which had tops of 10,000 ft.

Hurricane Nanette

Ships reported southeast winds up to 20 kt in the Gulf of Tehuantepec at 1800 GMT on September 2 and 0000 GMT on September 3. This was the first indication of the low-pressure circulation that developed into hurricane Nanette. Satellite pictures on July 3 revealed extensive intertropical convective activity and some cyclonically curved lines of clouds in the area, but no circulation center was evident.

At 1800 GMT on September 4, a developing circulation was shown to be of tropical storm intensity by a ship that reported 35-kt easterly winds and a pressure of 1008 mb from its location 50 n.mi. south of Acapulco. The ESSA 8 picture indicated that the ship-reported wind was associated with a dense, round cloud mass, about 60 n.mi. in diameter, located 90 n.mi. south of Acapulco. Loose banding in arcs of cumulonimbus with profuse cirrus outflow was apparent around this cloud mass.

The storm intensified to hurricane strength within about 30 hr while moving toward the northwest and approaching the coast. Cirrus outflow obscured all detail on the September 5 ESSA 8 picture. At 0000 GMT on September 6, the *President Madison* (KQQE) reported 50-kt south winds, wind waves of height code 12, and swell height of code 15 (combined sea about 30 ft) Pressure had risen 6 mb in 3 hr to 1002.1 as the ship was moving away from the small, new hurricane. ESSA 9 pictures taken about the same time were used to classify the storm as "Stage B."

The ESSA 8 picture at 1640 GMT on September 6 showed cirrus outflow obscuring most of the convective cloud banding in the hurricane, but there was indication of a tightly wound center in faintly visible lines outlining a comma-shaped cloud with a round head 50 n.mi. in diameter. Detail on the hurricane structure came from a U.S. Air Force reconnaissance fix at 19°19′N, 106°05′W at 1900 GMT. Maximum flight-level wind was a measured 80 kt; the strongest surface winds also were estimated at 80 kt. There was a 10-n.mi. diameter circular eye with a 12,000-ft high, closed wall. The wall and feeder bands showed clearly on radar. Dropsonde reported the central pressure at 990 mb, but at 2000 GMT a ship outside the eye on the southeast side of the storm reported 984-mb pressure and force 8–9 winds. A second reconnaissance fix at 2100 GMT reported that maximum surface winds had increased to 85 kt. The concurrent ESSA 9 picture was used to classify the storm as "Stage C."

This small, violent hurricane, which had been approaching the mainland on a track toward the northwest, then turned to the west at the mouth of the Gulf of California and weakening started.

The ESSA 8 picture taken at 1731 GMT on September 7 indicated a much weaker storm. Only narrow bands of clouds were visible in the north semicircle although cirrus outflow continued west and southwest of the center. At 1825 GMT, a reconnaissance flight reported winds to 65 kt at the surface, 60 kt at the 700-mb flight level, and pressure at 996 mb. The wall cloud was open on the east and southeast. Eye temperature at 700 mb was a warm 17°C; the wall cloud temperature was 11°C. Two and one-half hr later, the opening in the wall had rotated to the north and east sides, the eye temperature had risen to 18°C, and the wall area had warmed to 17°C at the point of reconnaissance penetration. Other conditions were about the same as on the initial fix. ESSA 9 pictures at 2230 GMT again indicated a "Stage C" classification.

Nanette weakened steadily and lost all circulation during the 48 hr after the September 7 reconnaissance report. Movement was toward the west-southwest. Stable inflow to the south semicircle of the disintegrating storm was evident on satellite pictures taken September 8.

Hurricane Olivia

The eye of Caribbean hurricane Irene moved onto southern Nicaragua, where terrain is relatively low, at about daybreak on September 19. By late afternoon, the remains of Irene with 30-kt winds were centered near the east shore of Lake Nicaragua. The lake may have contributed to the regeneration that was clearly well underway when an ESSA 8 picture was taken at 1516 GMT on September 20. Maximum winds were estimated from the picture to be about 50 kt. The center of the regenerated storm in the Pacific, renamed Olivia, appeared about 50 n.mi. west of Managua, Nicaragua. Inflow from the ITCZ was marked by multiple bands of cumulonimbus. Anticyclonic outflow was apparent in the profuse cirrus in the south semicircle and also east of the mountains of Guatemala. ESSA 9 pictures a few hours later had a "Stage B" appearance.

The ESSA 8 picture taken September 21, in which outer banding could be seen around the edges of the heavy cirrus outflow, indicated a general tightening of the lower cloud spiral. Hurricane intensity with surface winds as strong as 70 kt and a minimum sea-level pressure of 990 mb was revealed in the 2122 GMT fix by the Atlantic hurricane hunters. The 20-n.mi. diameter eye and feeder bands appeared on radar as a well-organized vortex; however, the top of the wall clouds was below 10,000 ft and the eyewall was open to the southwest through west. The 70-kt surface winds were found 25 n.mi. north of the center and there were 50-kt winds 50 n.mi. out to the north. In the ESSA 9 pictures concurrent with the reconnaissance flight, the storm still had the appearance of a "Stage B" system.

Olivia appeared on the southeast corner of an ESSA 8 picture made over Texas at 1653 GMT on September 22; little detail was apparent. The detail was provided by

Atlantic hurricane hunters during an eye fix at 2120 GMT. Maximum surface winds were still about 70 kt while minimum sea-level pressure of 983 mb was 7 mb lower than the pressure on the 21st. The wall around the 20-n.mi. diameter eye had built up to 15,000 ft in thunderstorms in the northeast quadrant but was still only 8,000 ft high in the southeast and northwest quadrants. Radar presentation of the cloud vortex was well defined and showed feeder bands to the northeast and southeast. The 18°C eye temperature at 700 mb was 4° warmer than on Septemper 1, but temperature outside the eye was 16°C. ESSA 9 pictures indicated a "Category 2, diameter 3" storm with 60-kt maximum winds.

The 700-mb temperatures and the relatively low eye wall on September 21 and 22 suggest that the feeder bands were acting as a main source of the warm midtropospheric air that was accumulating in a broad central section of the hurricane.

The ESSA 8 pictures taken September 23 contributed little information because the signal from the satellite was lost just as Olivia was appearing on a picture centered at 12°N, 90°W. Atlantic hurricane hunters obtained detailed descriptions. Maximum surface winds were 80 kt, and eye pressure was 981 mb. The eye had become elliptical. Severe turbulence was encountered in the wall on the northeast, which had built up to 20,000 ft. The eye was open to the west, and the vortex structure was clearly defined by radar echoes. Temperature in the eye at 700 mb was still 18°C, but the outside had cooled 2° to 14°C. On the 23d, maximum winds at the 700-mb flight level had increased to 58 kt from 55 kt on the 22d and 40 kt on September 21. The low eyewall prevailing during that period made the maximum flight level winds reasonably consistent with the considerably stronger maximum surface winds. ESSA 9 pictures taken on the 22d indicated a "Category 2, diameter 2" storm with 55-kt maximum winds.

Atlantic hurricane hunters made their fourth flight into the hurricane at 2349 GMT on September 24. In 24 hr, the central pressure had fallen 7 mb to 974 mb. The sea surface was not visible for a maximum wind estimate, but maximum measured flight-level winds were 55 kt. Radar definition of the wall clouds was good; tops were still comparatively low but had risen above the 700-mb flight level in all quadrants. Temperature contrast between the eye and wall area had increased to 6°C with the eye temperature (14°C) down 4° from the day before. ESSA 9 pictures indicated a "Category 2.5, diameter 2" storm with about 60-kt maximum winds.

ESSA 8 pictures taken September 25 showed a small round eye clearly visible (fig. 13); this was the basis for reclassifying Olivia to Category 4. The central overcast diameter of 3.5° of latitude resulted in an estimate of 100-kt maximum winds. A reconnaissance flight report and an ESSA 9 picture a few hours later were the basis for reducing this estimate to 90 kt.

The hurricane was still strong on September 26. Olivia appeared on the edge of pictures from two ESSA 8 orbits, so little information was gained. The 55th Weather Reconnaissance Squadron made two fixes, one at 1800 GMT and another at 2200 GMT. At 1800 GMT, the circular 17-n.mi. diameter eye had a pressure of 948 mb, the lowest reported in the eastern Pacific in 1971. Maximum surface winds of 100 kt were reported 20 n.mi. to the north while maximum 700-mb flight-level winds measured 90 kt. Eye temperature at 700 mb was 14°C and wall temperature was 11°C. The closed wall with feeder bands converging into the north side was well defined on radar. At 2200 GMT, eye pressure was 950 mb, maximum surface winds, 90 kt, and strongest 700-mb winds, 80 kt. Other details were unchanged since 1800 GMT. The concurrent ESSA 9 picture indicated a "Category 3.5, diameter 3" storm with about 85-kt maximum winds.

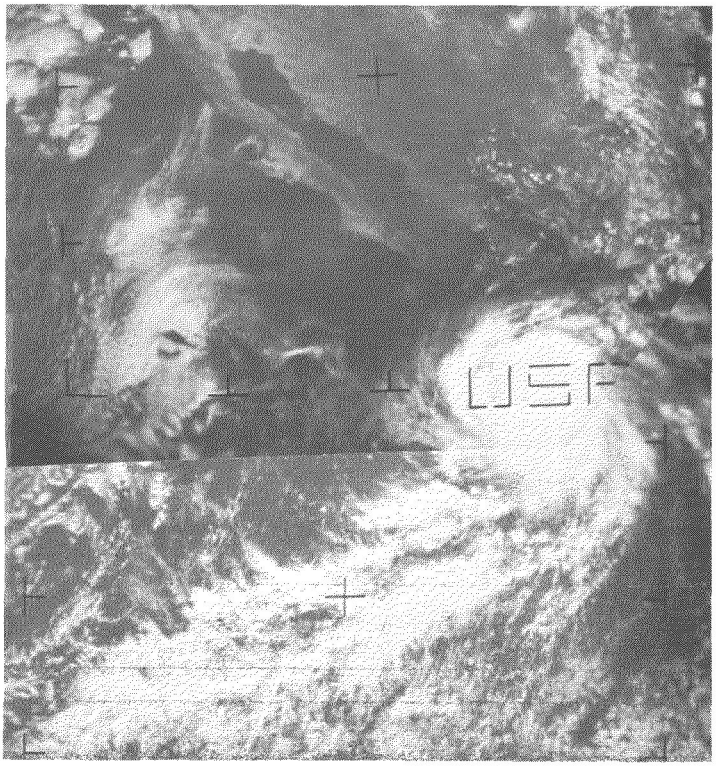

FIGURE 13.—ESSA 8 picture, orbit 12,730, Sept. 25, 1971. Olivia is a strong hurricane centered 200 n.mi. southwest of Manzanillo.

In the ESSA 8 picture on September 27 the eye was only dimly visible, and there was apparent stable surface inflow to the west edge of the hurricane from a stratocumulus sheet 300 n.mi. to the northwest. Ship reports within 100 n.mi. of the center indicated water temperatures of 22°–25°C in the northern semicircle within 100 n.mi. of the center.

U.S. Air Force reconnaissance confirmed a weakening trend at 2000 GMT on September 27. Pressure in the eye had risen to 963 mb and maximum surface and flight-level winds decreased to 80 kt. An opening had appeared on the southwest side of the 18-n.mi. diameter wall cloud. A feeder band from the southeast merged into the wall on the north. Temperatures at the 700-mb flight level were unchanged from those of September 26. The concurrent ESSA 9 picture showed a clearly visible eye and indicated a "Category 3.5, diameter 4" storm with 90-kt maximum winds.

The hurricane cloud system was disintegrating rapidly when viewed on an ESSA 8 picture taken September 28. The principal surface inflow appeared to be from the stable air on the northwest. Irregular openings 40–60 n.mi. across had appeared in the cloud system near the center and about 75 n.mi. out to the north. ESSA 9 pictures taken at 2154 GMT indicated a "Stage C" storm.

Remains of the cloud system appeared to consist entirely of stratified clouds in the September 29 satellite pictures, so Olivia was reclassified as a depression. All circulation was lost by the time of her landfall on Baja California near 27°N before daybreak on September 30.

Hurricane Priscilla

The seedling that developed into hurricane Priscilla crossed Panama October 4; this was shown by satellite pictures and ship reports (Frank 1971). A depression with 30-kt winds near 10.5°N, 90.0°W at 1800 GMT on October 6 was indicated by satellite pictures. The strengthening of Priscilla to tropical storm intensity was revealed a few hours after daybreak on October 7 by satellite pictures and ship reports. Wind speeds of 35–40 kt were reported about 100 n.mi. out in the northeast quadrant, but winds were light between there and the center; this indicated considerable shear vorticity in the relatively small central area of the storm and favored development (Simpson 1970).

Intensification continued. There was a ship report of 50-kt winds on the north side at 1200 GMT on October 8. A reconnaissance flight measured 72-kt winds at the 700-mb flight level in the northwest quadrant at 1734 GMT. Temperature in the 40-n. mi. diameter circular eye was 16°C and 12°C in the closed wall. Surface pressure in the eye was 984 mb. ESSA 9 pictures taken at 2008 GMT showed the eye clearly although the storm was near the edge of the picture. NESS placed the storm in "Category 3.5, diameter 2" and estimated 75-kt maximum winds.

A reconnaissance flight 24 hr later found that eye pressure had fallen 24 mb to a low of 960 mb. The circular eye had tightened to 18 n.mi. in diameter and the closed wall cloud extended vertically to 35,000 ft. The 700-mb eye temperature had warmed 4° to 20°C, and the wall had warmed 2° to 14°C. The 73-kt maximum wind found at 700 mb was measured in the northeast quadrant of the storm. This wind speed is an enigma considering the other indications of strengthening. The belt of maximum winds presumably was quite narrow and perhaps subject to pulsations of a few minutes duration, and winds may have been measured in the quadrant during a relative lull in wind maxima. Surface winds of 90–100 kt were estimated on the basis of the 960-mb central pressure, warmer core, smaller eye, and satellite pictures. NESS placed the hurricane in "Category 4, diameter 2.5" and estimated 90-kt maximum winds.

A reconnaissance flight found Priscilla still stronger at 1723 GMT on October 10. Central pressure had fallen to 951 mb, 700-mb winds as strong as 105 kt were measured, and surface winds as strong as 110 kt were estimated. The eye was still circular with an 18-n.mi. diameter and a closed wall extending up to 35,000 ft. The temperature in the eye, 20°C, was unchanged from the previous day, but the eye wall had cooled 3° to 11°C. This cooling of the wall cloud suggested surface inflow off cooler water or less addition of heat to the inflow from the ocean surface before the inflow rose in the eye wall chimney. Ship reports of sea-surface temperatures under the inflow were about the same as they had been on the day before; the reason for reduced heating by the ocean surface or the possibility of unrelated cooling processes is open to speculation. The radius of 50-kt flight-level winds was only 40 n.mi, and that of 30-kt winds was 75 n.mi. The tightened circulation raised the question of dynamic instability from anticyclonic shear outside the eyewall wind maximum (Simpson 1970).

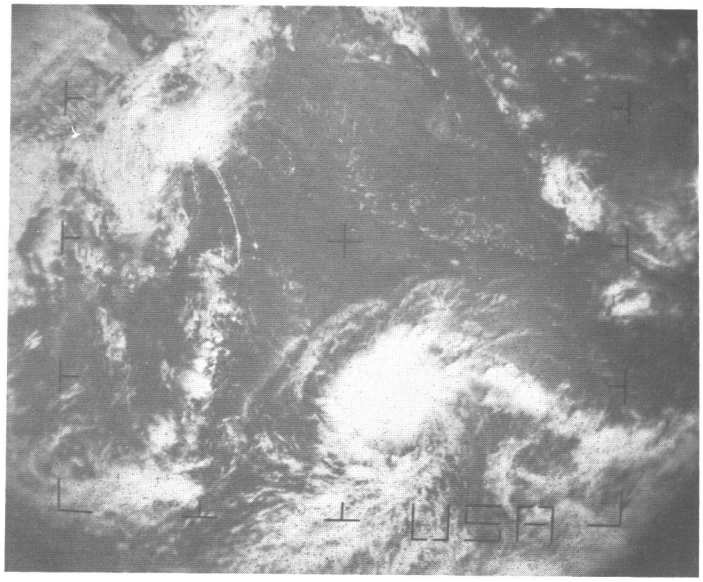

FIGURE 14.—ESSA 8 picture, orbit 13,144, Oct. 28, 1971. Tropical storm Ramona is centered 500 n.mi. south of Manzanillo.

Central pressure rose 21 mb to 972 mb in the 24-hr interval prior to the October 11 reconnaissance. Maximum winds at 700 mb had decreased to 80 kt, the eye had expanded slightly to 20 n.mi. in diameter, and the wall cloud had opened on the southeast. The entire south side of the eyewall appeared to be expanding and dissipating. Temperatures in the eye and eyewall (20° and 11°C, respectively) were unchanged from those of the day before. Satellite pictures were interpreted as "Category 3, diameter 2.5" with 70-kt maximum winds.

The weakening began just in time to save the San Blas area of the Mexican coast from a destructive hurricane. Landfall was made in that vicinity about daybreak on October 12, with maximum winds estimated at about 50 kt. No reports of damage reached San Francisco.

Tropical Storm Ramona

Ramona was discovered near 11°N, 104°W on an ESSA 8 satellite picture taken at 1703 GMT on October 28 (fig. 14). The anticyclonic outflow in the cirrus formation and the cyclonically curved area of lower cloud bands to the south

were interpreted as indicating a young tropical storm. Increasing cyclonic circulation was inferred from an ATS 3 movie loop made in NESS just prior to the ESSA 8 picture. No evidence of the beginnings of a storm cloud system could be seen on the satellite pictures taken the previous day.

A WC–135B reconnaissance aircraft investigated the storm area at 1800 GMT on October 29. Findings were summarized by the flight meteorologist: "NO EYE CENTER OBSERVED VISUALLY OR ON RADAR. CB TOPS 350 IN LINES BUT NOT IDENTIFIABLE AS RAIN BANDS. AREA OF CB 100 NM IN DIAMETER. CI SHIELD TOPS 370 200 NM IN DIAMETER. SFC WAS VSBL SEVERAL TIMES. NO ORGANIZED PATTERN TO LOW CLOUDS." The concurrent ESSA 8 picture showed the cirrus shield, which completely obscured the cumulonimbus; no external banding was evident. The weak appearance of the circulation in the picture led to the conclusion that a minor tropical storm had been present the day before and had begun to weaken.

Ship reports indicated that a weak low-pressure circulation with heavy showers and winds as strong as 25 kt persisted through October 30. All evidence of a closed circulation disappeared by October 31

Tropical Storm Sharon

The ESSA 8 picture taken at 1551 GMT on November 25 indicated weak cyclonic activity in the north edge of the ITCZ cloudiness near 9.5°N, 100.5°W. A ship report 8 hr later and 50–75 n.mi. north of the area reported 25-kt easterly winds, 1008.8-mb pressure, 4.5-ft wind waves, and an 8-ft easterly swell.

Evidence of increased organization was clear in the satellite pictures taken November 26. Considerable anticyclonic cirrus outflow was apparent, and arcs of low-level cumulonimbus bands could be seen extending under the cirrus cap at a steep angle. Peak strength in the weak tropical storm range, with maximum winds somewhat less than 40 kt, apparently was reached on the 26th.

A reconnaissance at 1731 GMT on the 27th found maximum surface winds to 30 kt in the northwest quadrant, 42 n.mi. from the center, and only 20-kt maximum winds in the south semicircle. A partial, weak wall cloud was found on the north side of the center, which had a 700-mb temperature of 10°C, 2° warmer than outside. Pictures concurrent with the reconnaissance flight showed that the storm looked much less like a tropical storm than it did in pictures from the previous day. Dissipation was complete within 24 hr. An ESSA 8 picture at about 1500 GMT on November 28, showed only an amorphous cloud mass and shower activity in the area.

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